

**Intermediate Energy Physics in the Strangeness  
Sector with Hyperon Beams**

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## Hyperons, et al

- Production Mechanisms  
OBE vs Quark Mechanisms
- Spectroscopy  
Baryons and Mesons
- NN → Strange sector  
Hyper nuclei  
FSI and scattering  
Isospin violations  
Many body & media modifications
- Weak Interactions  
 $\Delta I = \frac{1}{2}$  rule decays  
CP violations

# Production Mechanisms

$$p\bar{p} \rightarrow Y\bar{Y}^*$$

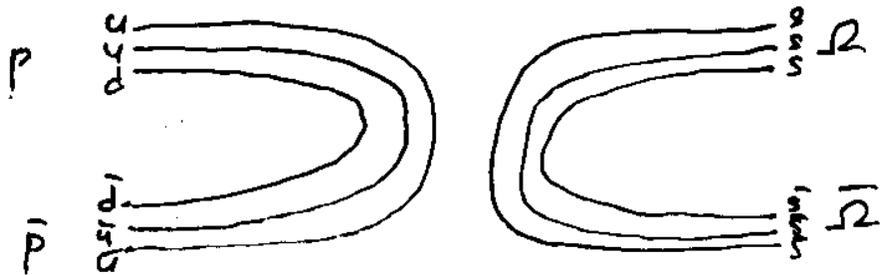
quark vs OBE

nature of  $\Lambda(1405)$   $\Lambda^*$  or  $KN$  molecule

$\Xi\bar{\Xi}$  (out of reach of LEAR)

$> 2.6 \text{ GeV}/c$   $\bar{P}$  beam

$\Omega\bar{\Omega}$

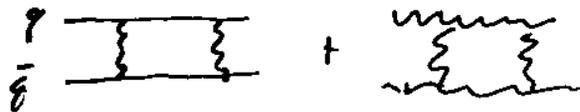


# Spectroscopy

## Light Mesons

Glueball sector very active

- Scalar Glueball Mixed States  
Crystal Barrel  $f(1500)$ , etc  
Need theoretical guidance



- Hybrids with Exotic Quantum Numbers

BNL E852

18 GeV/c pion beam

1370 MeV/c<sup>2</sup> JPC = 1<sup>-+</sup>

PRL 79 (Sep. 97)

(+NPR, CNN, Pittsburgh Post Gazette...)



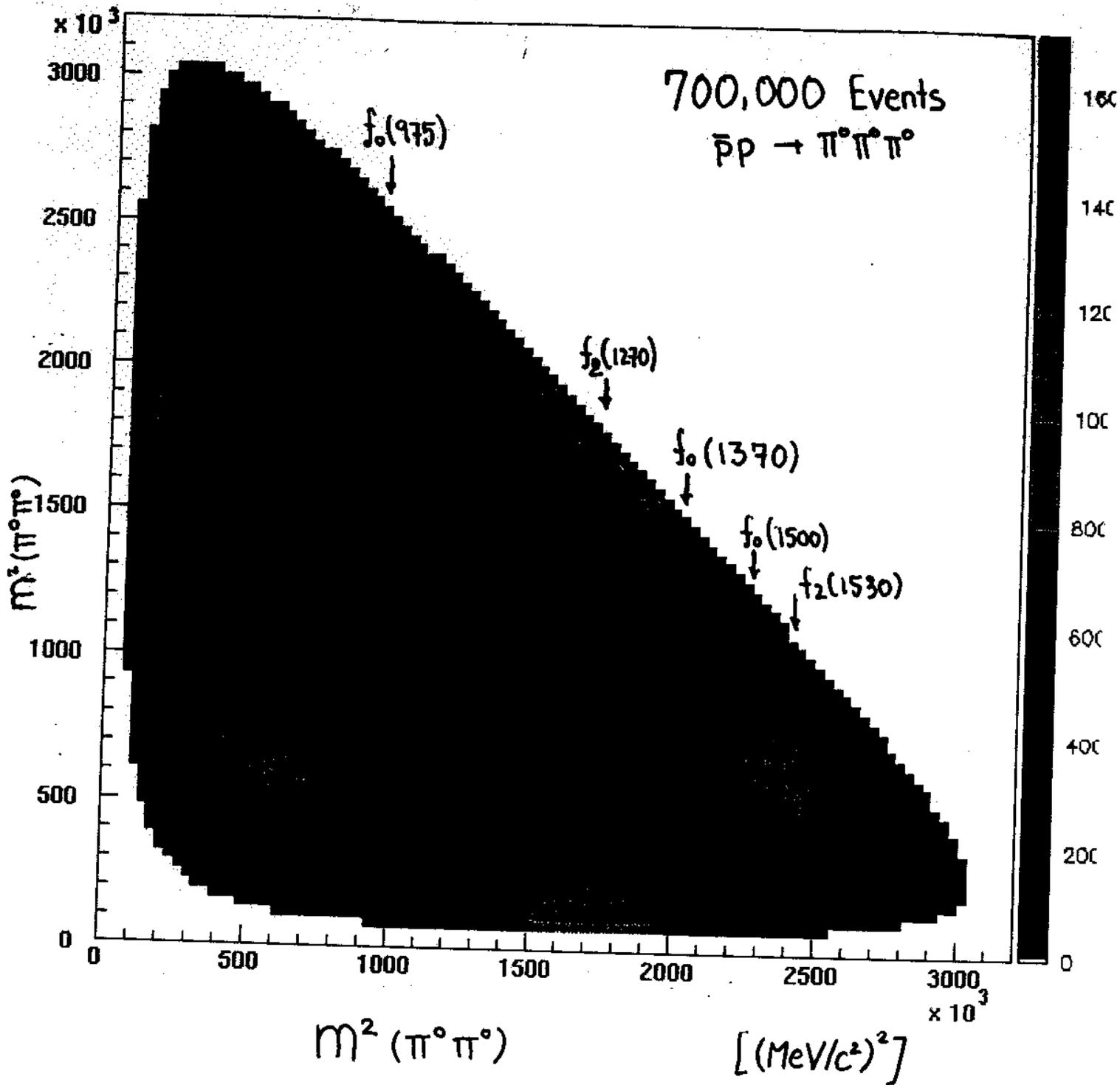
- Tensor Glueball

$\xi(2230)$  now confirmed at BES

not seen in  $p\bar{p}$  (PS185, Crystal Barrel)

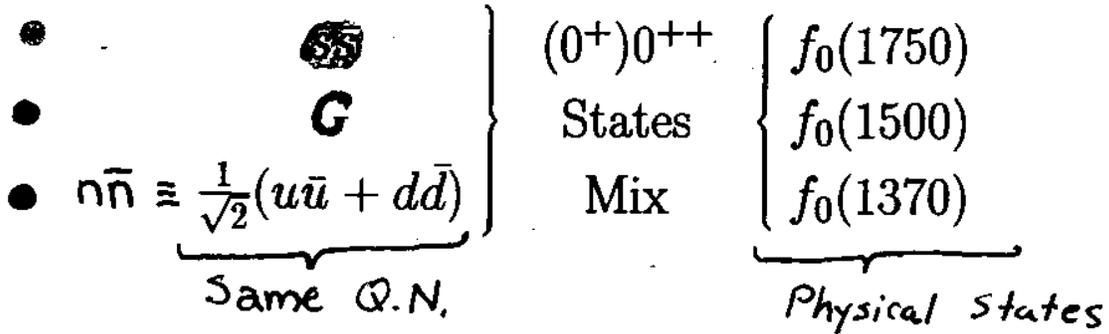
AGS E924 D. Hertzog et al

When will it be done?

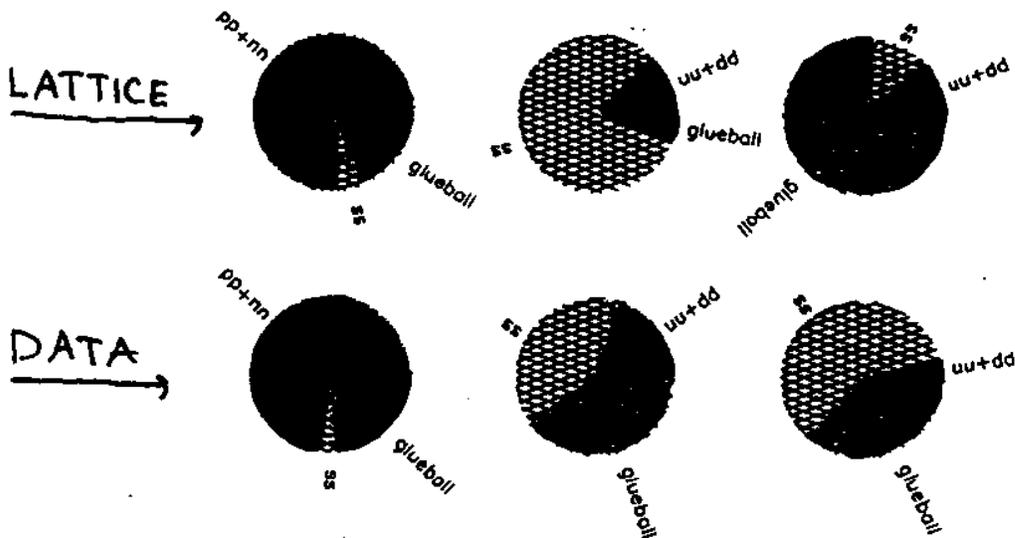


# The Scalar Sector

- $f_0(1500)$  and  $f_0(1750)$  ( $f_J(1710)$ ) Glue-rich Production.
- $f_0(1500)$  has a peculiar decay pattern – not pure glueball.
- $f_0(1750)$  decay pattern not so clear.



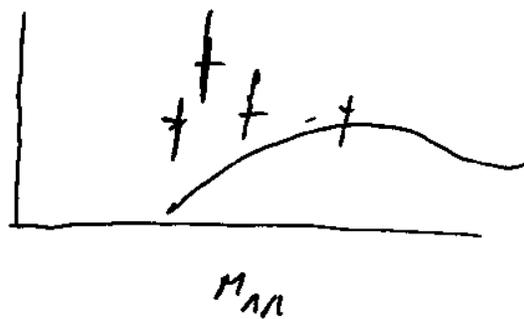
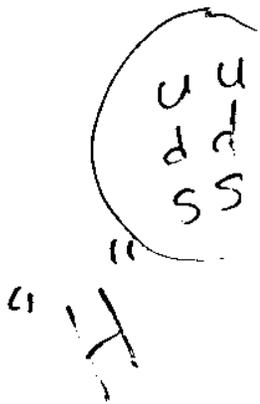
	MIXING	$\longrightarrow$	<u>Lattice Inspired</u>	$\longrightarrow$	<u>Data Inspired</u>
			$f_{i1}^{(n)}$ $f_{i2}^{(s)}$ $f_{i3}^{(G)}$		$f_{i1}^{(n)}$ $f_{i2}^{(s)}$ $f_{i3}^{(G)}$
$f_0(1370)$	—		0.87   0.25   -0.43	—	0.86   0.13   -0.50
$f_0(1500)$	—		-0.36   0.91   -0.22	—	0.43   -0.61   0.61
$f_0(1750)$	—		0.34   0.33   0.88	—	0.22   0.76   0.60
			$f_0(1370)$ $f_0(1500)$ $f_0(1750)$		

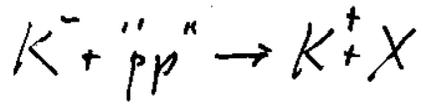


# Spectroscopy

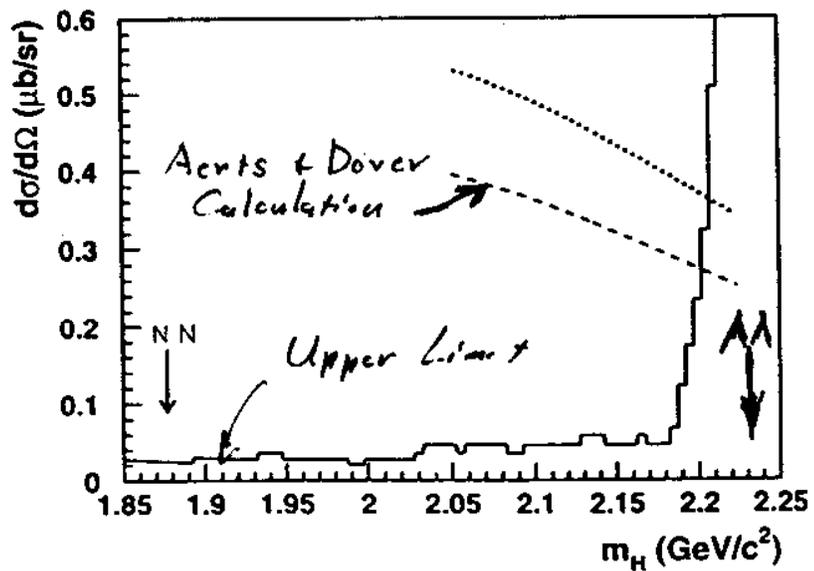
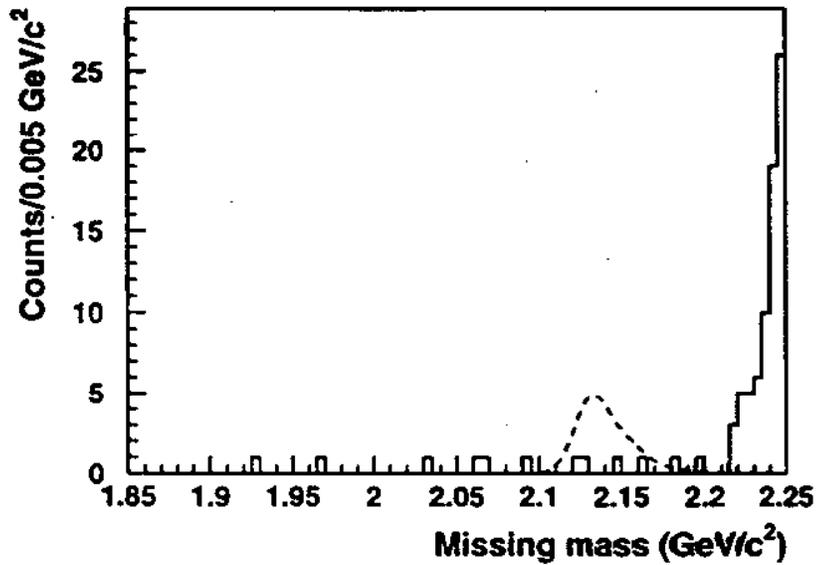
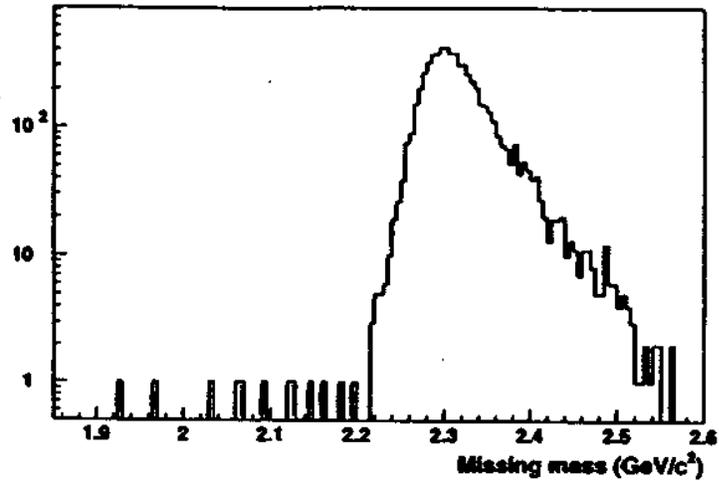
- Baryons  
3q systems largely unexplored  
(memo of D. Peaslee)
- Dibaryons  
S=-2 systems ideal for AGS

KEK  $\Lambda\Lambda$  invariant mass spectrum  
shows strength at low  $\Lambda\Lambda$  mass (fsi?)  
from  $K^- + {}^{12}\text{C} \rightarrow K^+ + X$

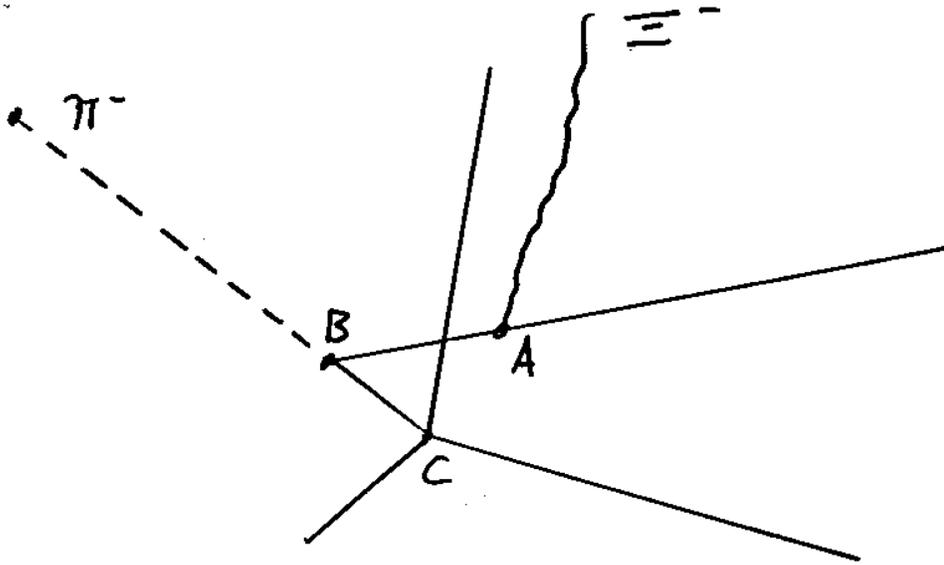




Search for the H



# Hyperfragments in Emulsion



Target: O, N, C, H, Ag, Br

Need: 2 delayed decay vertices B+C  
 $\pi^-$  emission

Note: Mass of hyperfragment at B  
gives ground state mass of  $S=-2$  system.

Lower limit on H mass.

## Do $\Lambda\Lambda$ Hypernuclear Events Rule out a bound H?

Statement:

"The KEK event shows the binding of the H cannot be greater than 27 MeV."

Equivalent Statement:

"A hypothesis that the H exists with  $B_H > 27$  MeV contradicts emulsion data interpretation."

Why?

- Assume correct interpretation of event
- Assume hypernucleus reaches ground state before weak decay  ${}^{13}_{\Lambda\Lambda}B \rightarrow \pi^- + {}^{13}_{\Lambda}C$
- Expect  ${}^{13}_{\Lambda\Lambda}B \rightarrow {}^{13}_H B$  if energetics allow  
*no metastable state?*
- Contradicts measured mass

Is light H ruled out?

Maybe

Is weakly bound H ruled out?

No

## Stopped $\Xi^-$ emulsion experiments

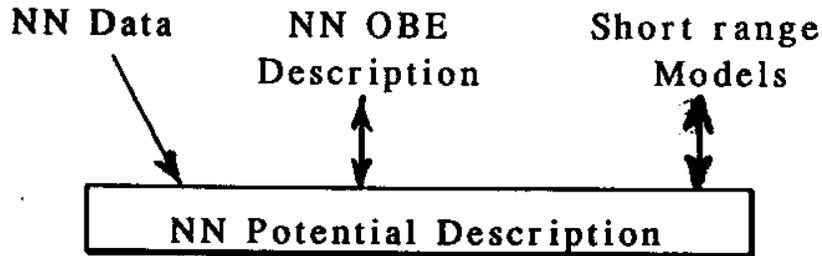
- Measure  $\Lambda\Lambda$  ground state via  $\Lambda \rightarrow p\pi^-$  decay mode (only possible in light hypernuclei)
- Low K flux requirements (but need good K/ $\pi$  ratio)
- 3 reconstructed events identified in 30 years.
- 3 more recently observed  $\Lambda\Lambda$  hypernuclei nonmesonic decays species and binding not determined
- $\Lambda\Lambda$  Hypernuclei exist,  $\Delta B_{\Lambda\Lambda}$  probably positive, but...

	#K <sup>-</sup>	stops	B <sub>ΛΛ</sub> (MeV)	ΔB <sub>ΛΛ</sub> (MeV)
<ul style="list-style-type: none"> <li>• Danyz <i>et al.</i> 1963  <math>{}_{\Lambda\Lambda}^{10}\text{Be} \rightarrow {}_{\Lambda}^9\text{B} + p + \pi^-</math>  <math>\quad \quad \quad \downarrow</math>  <math>\quad \quad \quad \rightarrow \alpha + \alpha + p + \pi^-</math></li> </ul>	10 <sup>5</sup>	~2	17.7 ± 0.4	4.3 ± 0.4
<ul style="list-style-type: none"> <li>• Prowse 1966  <math>{}_{\Lambda\Lambda}^6\text{He} \rightarrow {}_{\Lambda}^5\text{He} + p + \pi^-</math>  <math>\quad \quad \quad \downarrow</math>  <math>\quad \quad \quad \rightarrow \alpha + p + \pi^-</math></li> </ul>	10 <sup>6</sup>	~30	10.9 ± 0.8	4.7 ± 1.0
<ul style="list-style-type: none"> <li>• Aoki <i>et al.</i> 1990  <math>{}_{\Lambda\Lambda}^{10}\text{Be} \rightarrow {}_{\Lambda}^{10}\text{B} + \pi^-</math>  <math>\quad \quad \quad \downarrow</math>  <math>\quad \quad \quad \rightarrow {}^3\text{He} + \alpha + p + n + n</math></li> </ul>	10 <sup>9</sup>	80	8.5 ± 0.7	-4.9 ± 0.7
OR: ${}_{\Lambda\Lambda}^{14}\text{C}^* + n \rightarrow {}_{\Lambda\Lambda}^{13}\text{B} + p + n$ $\quad \quad \quad \downarrow$ $\quad \quad \quad \rightarrow {}_{\Lambda}^{13}\text{C} + \pi^-$ $\quad \quad \quad \downarrow$ $\quad \quad \quad \rightarrow {}^3\text{He} + \alpha + \alpha + n + n$			27.5 ± 0.7	4.8 ± 0.7

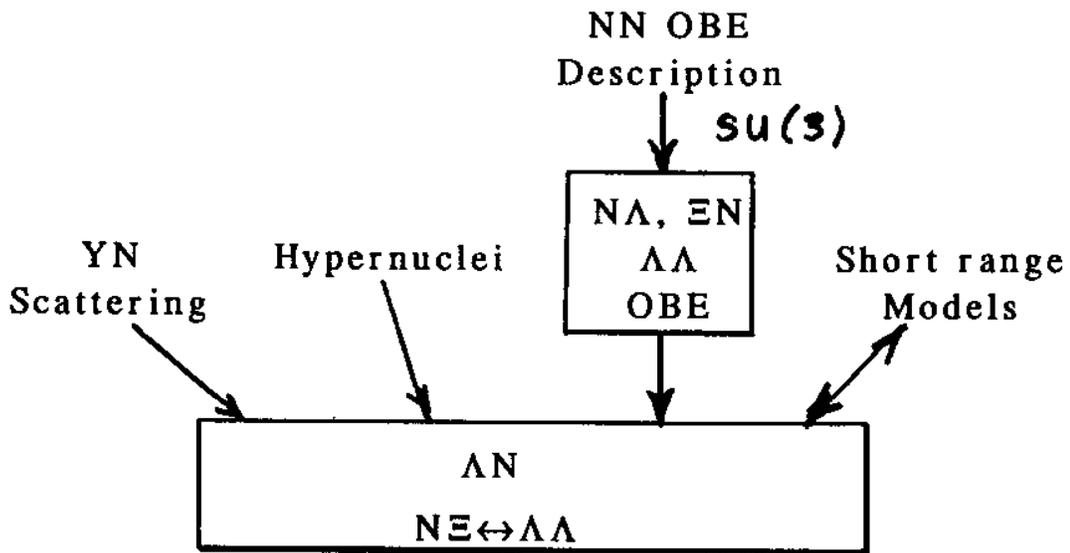
NN  $\rightarrow$  Strange Sector

The Baryon-Baryon Interaction

S=0

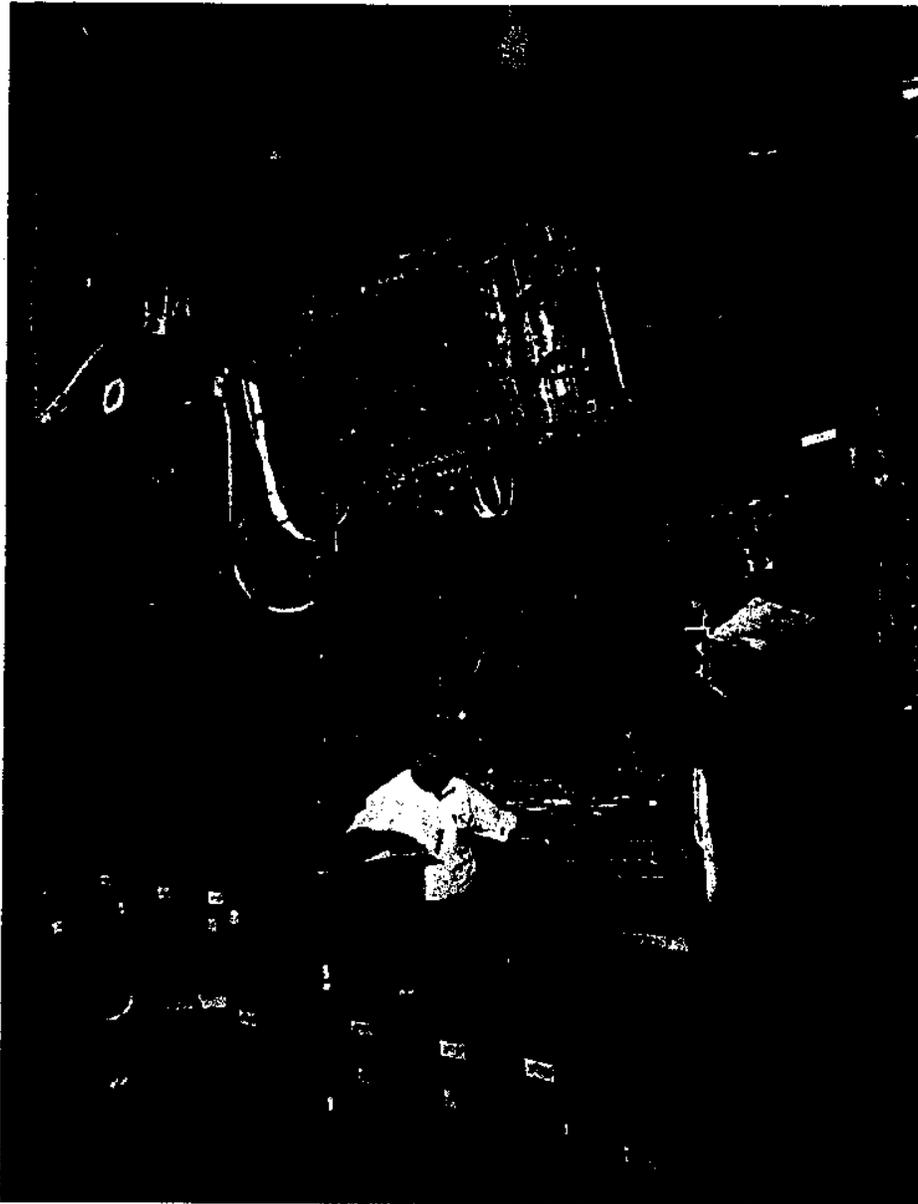


S= -1, -2

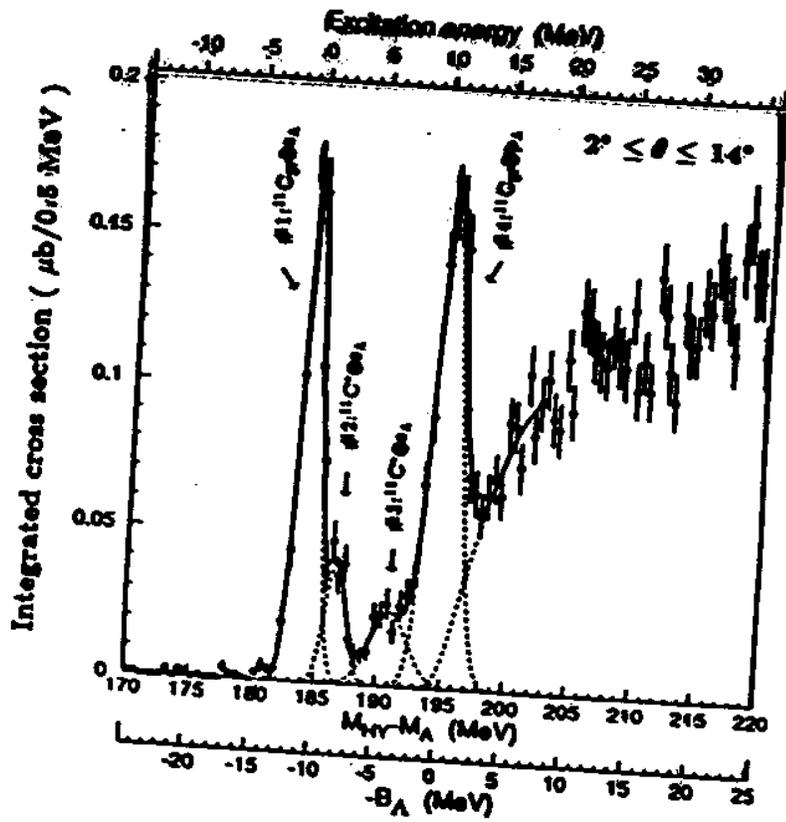
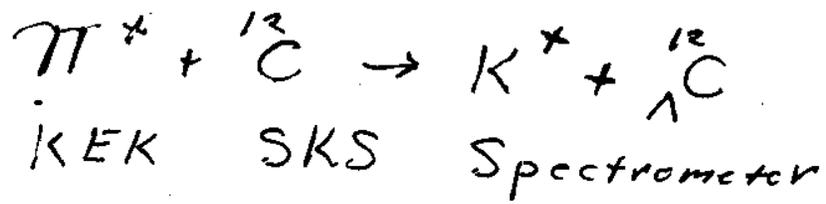


- Equivalent NN descriptors  $\rightarrow$  conflicting  $\Xi N, \Lambda\Lambda$

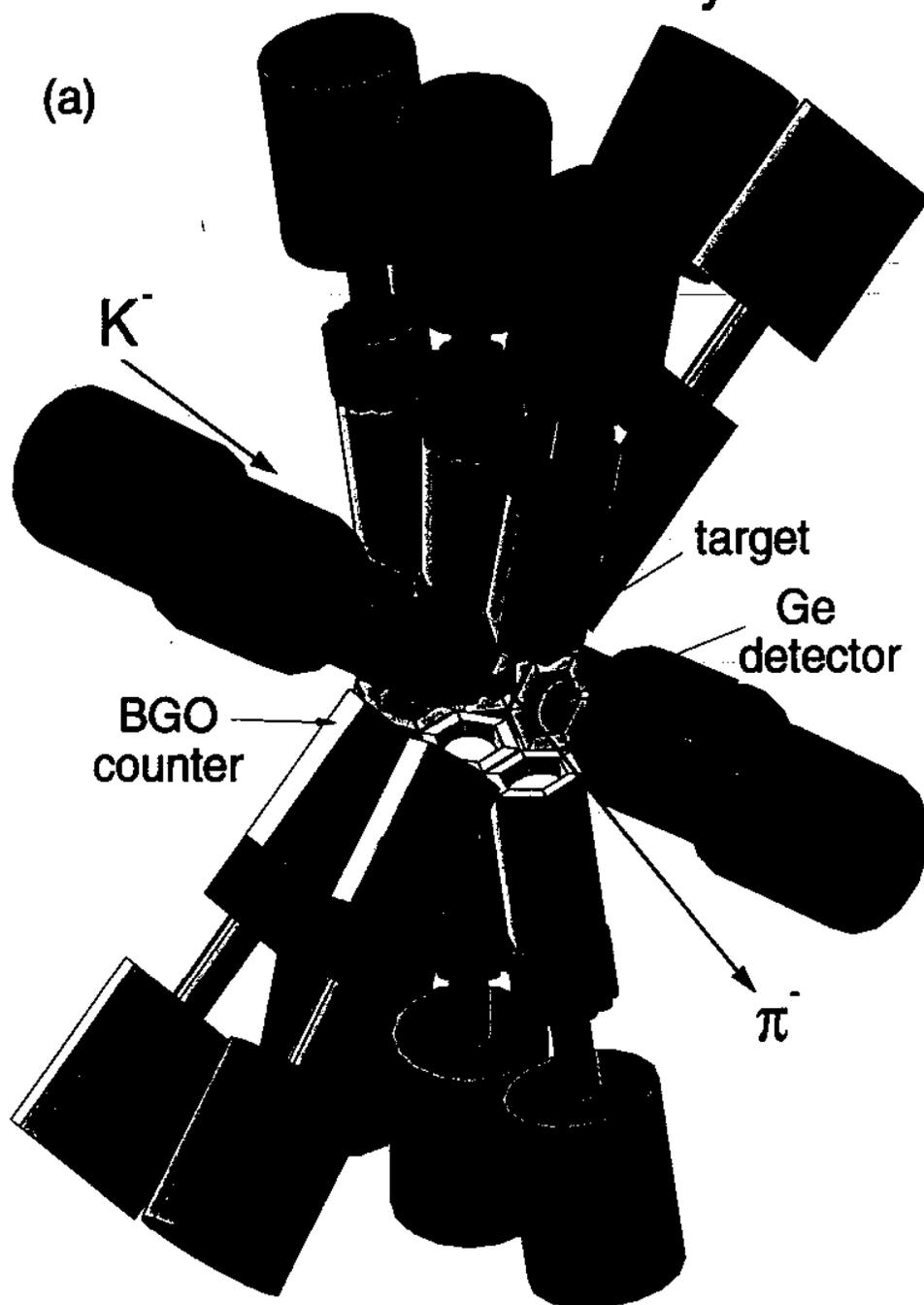
## The Neutral Meson Spectrometer at the AGS



Developed at Los Alamos for the detection of neutral meson, the spectrometer shown above has been assembled at the AGS C8 line, where it is being used for hypernuclear studies with the  $(K^-, \pi^0)$  reaction. The NMS detects neutral pions by detecting the pair of photons produced by the neutral meson decay, and measuring their energies and opening angles. The device opens up a whole new regime of "mirror" hypernuclei.

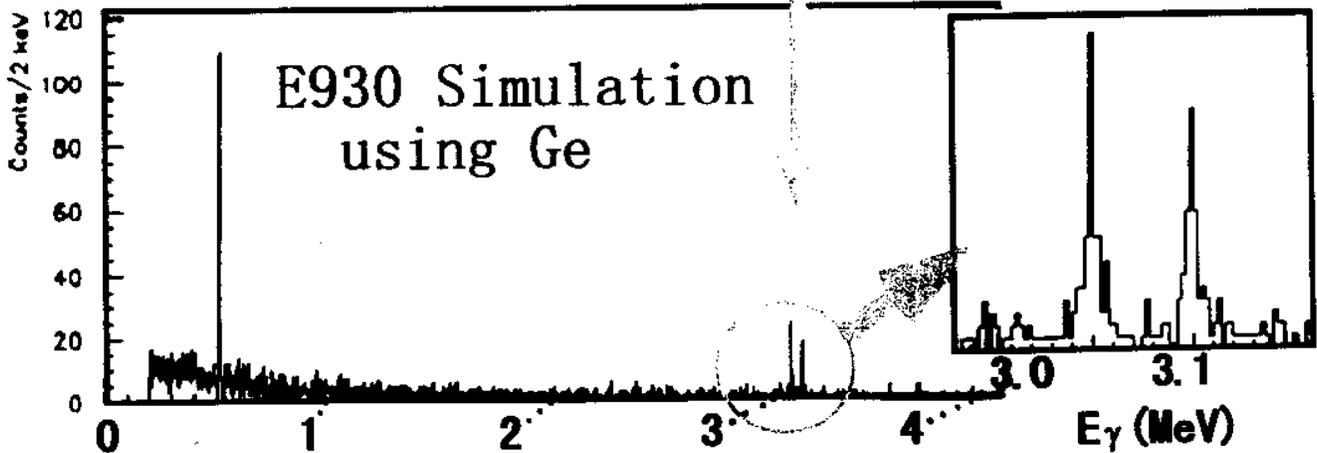
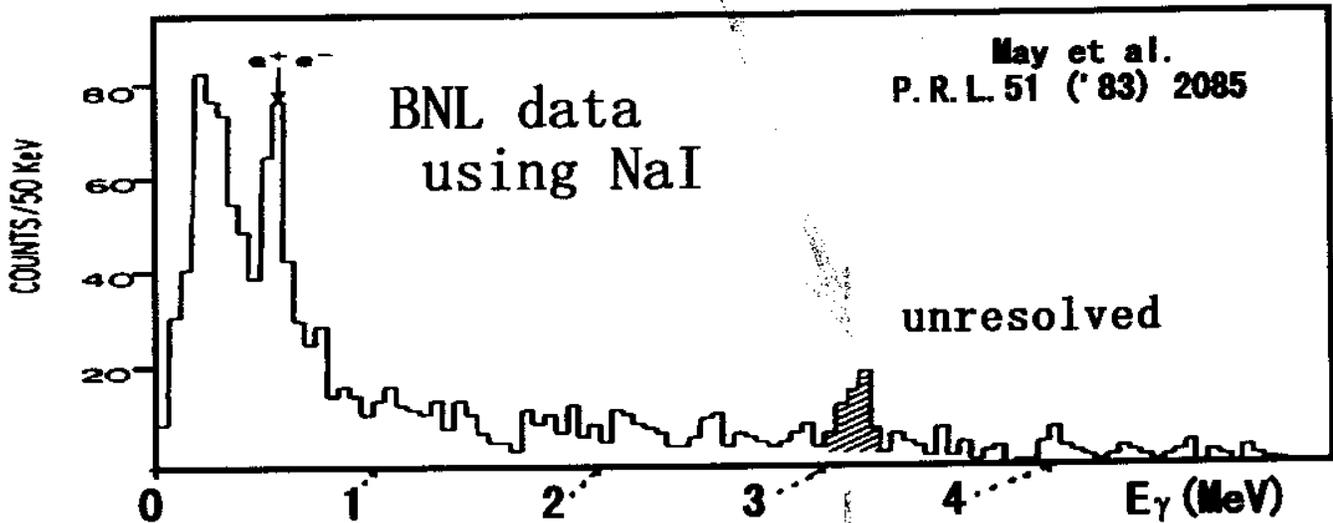
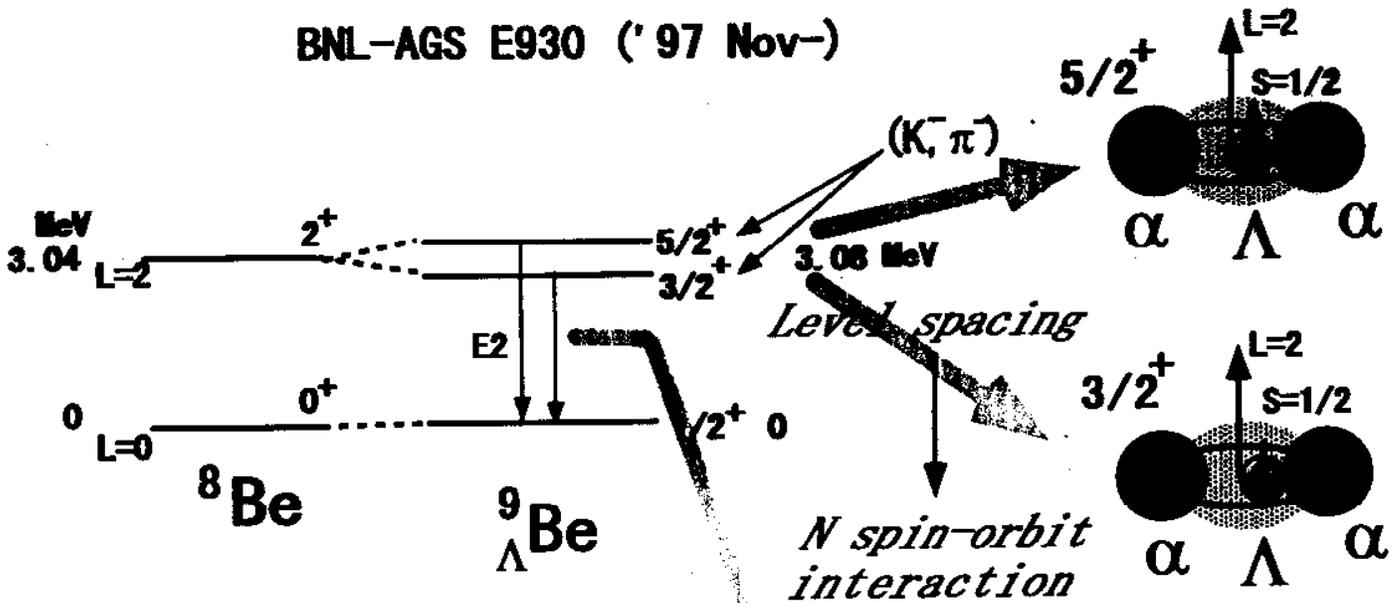


# Germanium detector system



# Spectroscopy of ${}^9_{\Lambda}\text{Be}$ , ${}^{16}_{\Lambda}\text{O}$ , etc.

BNL-AGS E930 ('97 Nov-)



## NN → Strange Sector

### **S= -1 Hypernuclei**

(K,  $\pi^0$ ) Neutral Meson Spectrometer  
(E. Hungerford et al)

(K,  $\pi\gamma$ ) Ge Detector System  
(H. Tamura et al)

### **S= -2 Hypernuclei**

Use of ( $K^-$ ,  $K^+$ ) to create S=-2 systems

Decay products yield level splitting

"S2S" proposal *LCI*  
100 ms superconducting spectrometer  
(modeled after KEK SKS)  
reasonable count rates (200 nb/sr)

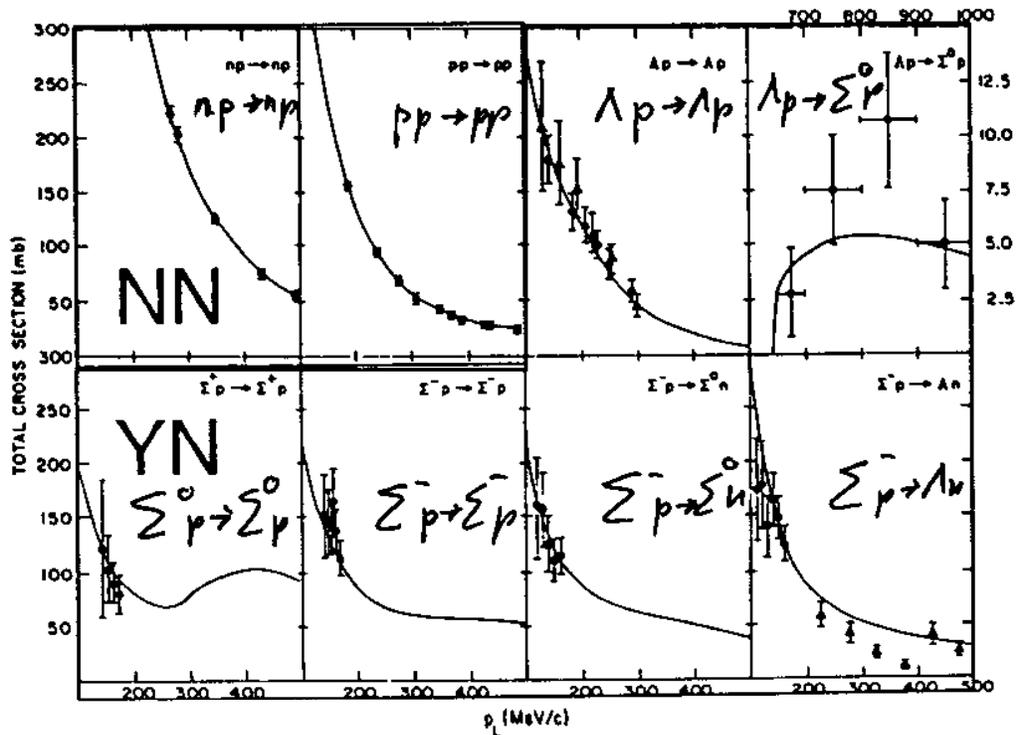
## NN $\rightarrow$ Strange Sector

### Final State Interactions and Scattering Experiments

#### Example

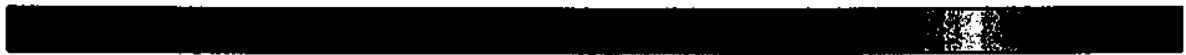
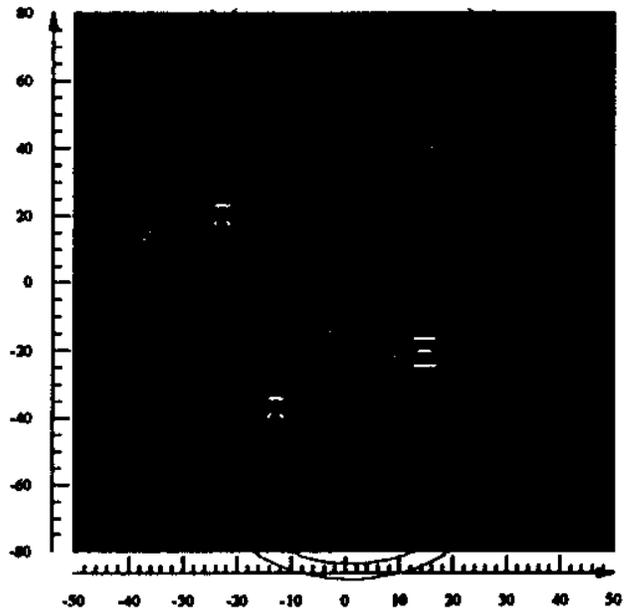
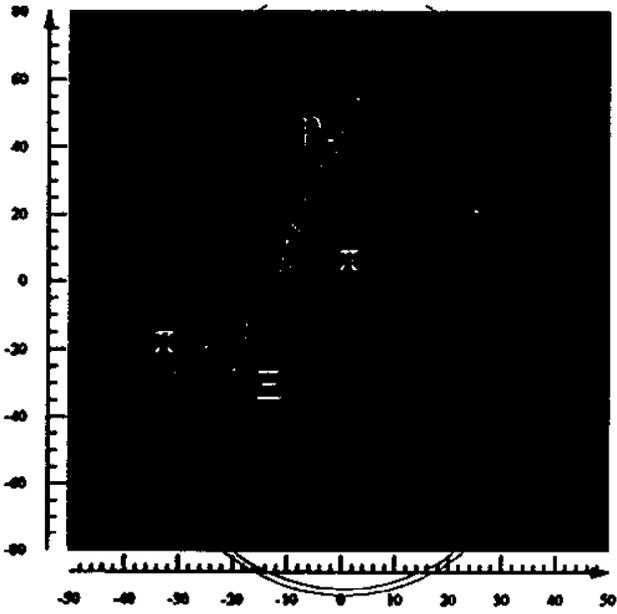
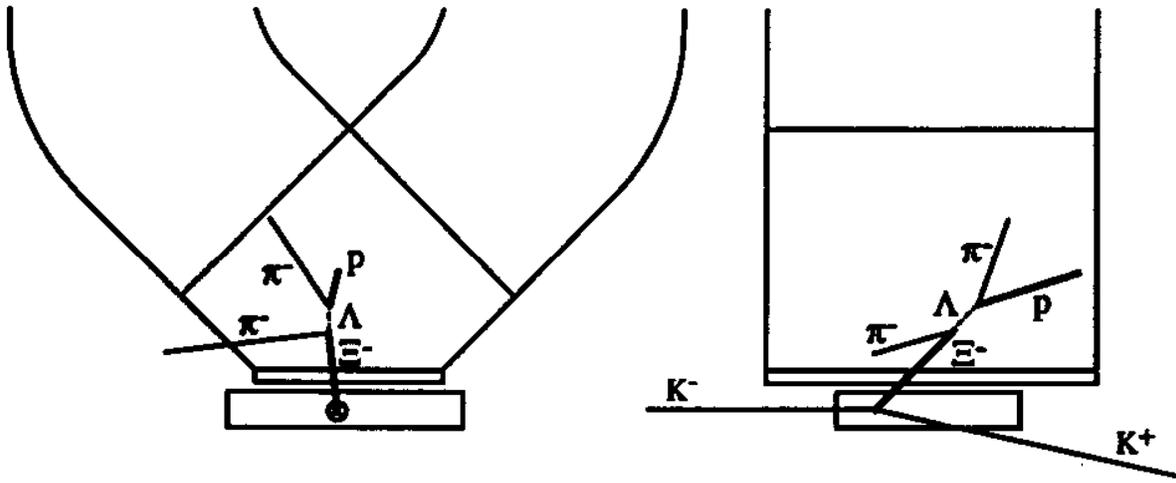
$$(\Xi, d)_{\text{atom}} \rightarrow \Lambda \Lambda n \quad (\text{Afnan et al})$$

Poor existing  $\Upsilon N$  data



from Dover & Feshbach Ann.Phys.198(90)321

AGS E 885



Use 2 GeV  $K^-$  line + CDS

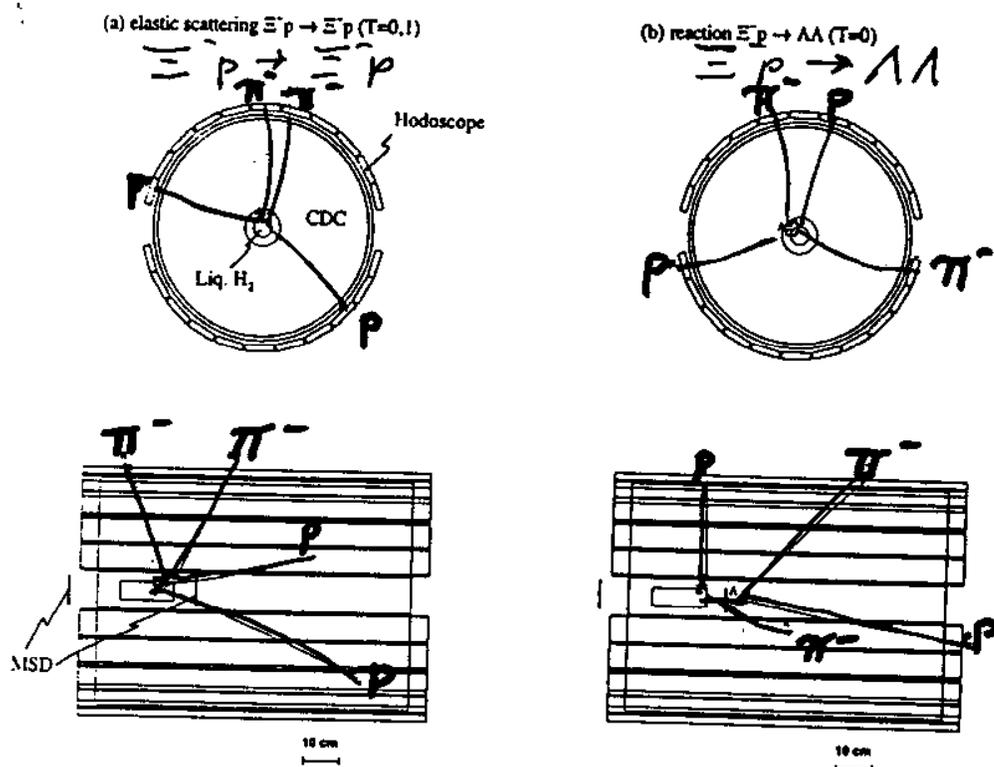
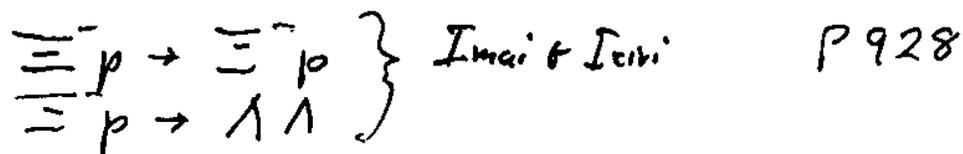


Fig. 1 A schematic drawing of a liquid hydrogen and the CDS. Typical events are also displayed in the figure: (a) elastic scattering  $\Xi^- p \rightarrow \Xi^- p$ , (b) reaction  $\Xi^- p \rightarrow \Lambda \Lambda$ .

NMS Collaboration

$$d(K^-, \pi^0 n) \gamma^0$$

→  $\Lambda n$  &  $\Sigma^0$  Interactions

Deinhard et al LOI

Data T.H. Tan  
 PRL 23 (1969)

Calculations

Tan et al PL 13174 (1986) Lambda-proton C.M. total energy (GeV)

existing  $d(K^-, \pi^0 p) \Lambda$  data

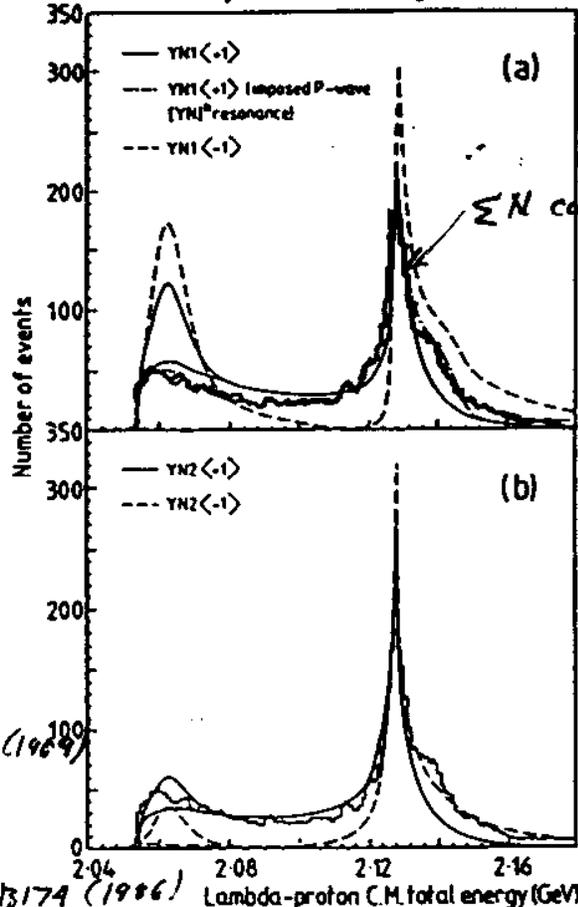


Fig. 1. The  $m(\Lambda p)$  spectra calculated for the parameter sets  $YN1(\pm 1)$  and  $YN2(\pm 1)$  given in tables 1 and 2 are compared with the data of Tan [2]. Below 2080 MeV, the lower branch of each curve gives the rate when only events with proton recoil momenta  $> 75$  MeV/c are counted. The effect of an imposed  $(YN)^*$  resonance is shown for  $YN1(+1)$ .

Fig. 1.  $\Lambda p$  total mass-energy spectra from the  $d(K^-, \pi^- p) \Lambda$  reaction using stopped kaons. Data of Ref.[4]. This is Fig. 1 of ref.[19].

## Weak Interactions

S=-1 Hypernuclei

$\Delta I = \frac{1}{2}$  rule and non-mesonic decays

mesonic decays

S=-2 Hypernuclei

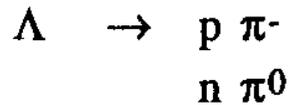
$\Lambda\Lambda \rightarrow n\Lambda$

$\Lambda\Lambda \rightarrow p\Sigma$

*related to NN parity violating terms*

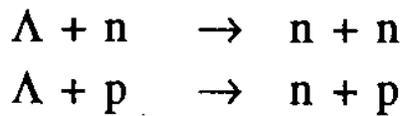
# Hypernuclear Decays and the $\Delta I=1/2$ Rule

Mesonic Decays



In Hypernuclear, mesonic rates reduced

**But...** also get nonmesonic decay modes

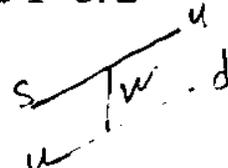


Do we understand electroweak in presence of QCD?

## Weak Strangeness Changing Decays:

$$\langle f | H_{\text{eff weak}} | i \rangle = \langle f | H_{\Delta I=1/2} + H_{\Delta I=3/2} | i \rangle$$

Example:  $\Lambda \rightarrow N\pi$  final state can be  $I=1/2$  and  $I=3/2$

First order, should have  $H_{\Delta I=1/2} \sim H_{\Delta I=3/2}$  

But empirical data  $H_{\Delta I=1/2} \sim 20 \times H_{\Delta I=3/2}$  for  $\Delta S=1$  transitions.

Explanation: QCD corrections + "accidents"

$K^0 \rightarrow \pi\pi$   $I=0$   $\pi\pi$  attraction enhances  $H_{\Delta I=1/2}$

$I=2$   $\pi\pi$  repulsive

Large violations in  $\Lambda N \rightarrow NN$  predicted.

Current tests

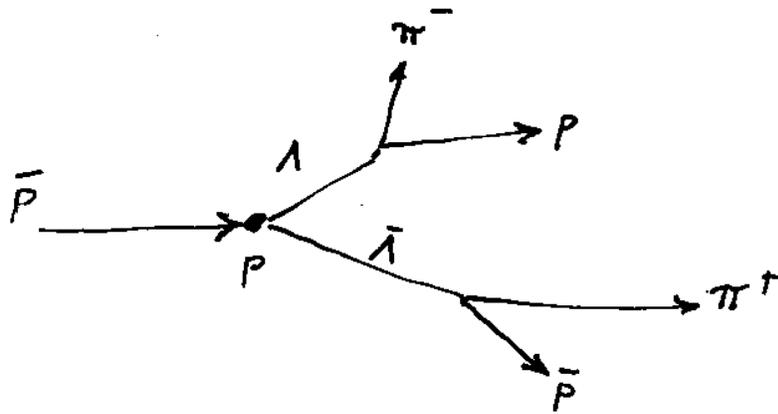
	$\frac{\Delta I=1/2}{\Delta I=3/2}$	Theory	Exp.
$\frac{\text{neutron stimulated rate } \frac{4}{\Lambda} \text{He}}{\text{proton stimulated rate } \frac{4}{\Lambda} \text{H}}$	= 2	~1	?

## Weak Interactions

$\eta$  decays (Crystal Ball collaboration)

$$\eta \rightarrow \pi^0 \mu^+ \mu^-$$

CP violation in  $\Lambda$  decay (Antiproton Group)



$$\frac{\bar{\alpha} - \alpha}{\bar{\alpha} + \alpha}$$

$$K^- + X \rightarrow K^+ + X_{S-2}$$

